Mathematical Modeling and Simulation of Frame under Earthquake Excitation

PROJECT SUBMITTED IN PARTIAL FULFILMENT
OF THE REQUIREMENTS FOR THE DEGREE OF

Bachelor of Technology
In
Civil Engineering

By

Anuj Verma

Department of Civil Engineering
National Institute of Technology, Rourkela
May, 2010

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Under the Guidance of
Prof. U. K. Mishra

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CERTIFICATE

This is to Certify that the thesis entitled , "Mathematical Modeling and simulation of frame under Earthquake Excitation"submitted by Mr. Anuj Verma in Partial fulfillment of the requirements for the award of Bachelor of Technology Degree in Civil Engineering at the National Institute of Technology , Rourkela (deemed University) is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date : 12/05/2010 **Professor U.K. Mishra**

ACKNOWLEDGEMENT

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Date : 14/05/10 **Anuj Verma**

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ABSTRACT

Earthquake excitation causes lots of damage. Modern structural protective systems can be used to reduce the damaging effect of destructive Earthquake forces. History of Structural design can be divided into three eras. Classical era dealt only static loads. Modern era of Structural design added with specifications on dynamic response. The Post modern era anticipates specifications on the dynamic response. By Energy dissipating devices the earthquake performance of the Structure can be improved. Among various Energy dissipating Mechanisms Tuned mass dampers, Viscous, viscoelastic (VE) dampers and Base isolation techniques are popular. Viscoelastic are the simplest Energy dissipating device. It can easily fit into the the structure without causing any disruption in the functional use. Since certain regions in India is highly venerable to Earthquake. Need was felt to simulate the Earthquake forces on the structure using MATLAB. Single storey structure was analyzed by solving 2 order differential equation for El Centro Earthquake data. Results of the displacement of structure was plotted on a graph and compared with the response of structure without VE dampers. The effects of linear viscous dampers in controlling the response multistory frame have been investigated. Seismic response of the structure was computed. It has been demonstrated numerically that the response of a frame structure may be reduced to desired level by providing external dampers. Reduction in response depends on the energy dissipated through external dampers. Due to inherent uncertainties in the external VE dampers, it is recommended that external dampers be symmetrically placed wherever possible. Equation of motion of frame under Earthquake was modeled. Linear Elastic System was considered for the analysis having Single degree of freedom. By solving the differential equations seismic responses of structure are computed. MATLAB is easy to use interface and can solve high order differential equations. Response of the structure to the VE dampers was satisfactory.

Chapter 1

Introduction

1.1 Introduction

The history of Structural Design divides into three eras. Much of the classical era for civil engineering design dealt with only static loads. The modern era of Structural design added with specifications on dynamic response (e.g. Specification on damping and mode shapes) Today, civil structures must be designed to satisfy static and dynamic requirements in the presence of specified range , or class of disturbances(external loads). The post modern era anticipates specifications on the dynamic response in some cases that are sever that they can only be met by feedback control, or at least by an integrated approach to the design of the structure and the feedback devices. This requires interdisciplinary research. The goals of the post modern era are to increase the survivability of the building in the presence of extraordinary excitation from winds and earthquakes.

The control of structural vibration produced by earthquake or wind can be done by various means such as modifying rigidity, masses, damping or shape and b providing active and passive counter forces. To date, some methods of structural control have been used successfully and newly proposed methods offer the possibility of extending applications and improving efficiency. Work on Structural control in civil engineering is relatively recent. It is now established that structural control can be an important part of designing new structures and retrofitting existing structures for earthquake and wind.

Structural Control has its roots primarily in aerospace related problem as tracking and pointing, and in flexible space structures, the technology quickly moved into civil engineering and infrastructure related issues such as protection of buildings and bridges from extreme loads of earthquake and wind. International Association for Structural Control (IASC) was formed as a governing body and sponsor for future conferences and workshops in 1994.

The notion of Structural control as currently defined can trace its roots back more than 100 years to John Milne, a Professor of engineering in Japan who built a small house of wood and placed it on ball bearing to demonstrate that a structure could be isolated form earthquake shaking. It was during the Second World War that the concepts of vibration isolation, vibration absorption and vibration damping were developed and effectively applied to aircraft frames.

Structural engineering community first embrace this technology in the 1960’s and since then it pursued a number of different paths; one example is base isolation for low rise and medium rise structures and bridges. The objective is to mount the structure in sufficiently flexible base that filters out the high frequencies of the ground motion and lightens the natural period of vibration to approximately 2s. Structural control has a distinctive feature that governs the direction of research

Chapter 2

Base Isolation Methods

2.1 Introduction

All vibrating structure dissipate energy due to internal stressing, rubbing, cracking, plastic deformations and so on; the larger the energy dissipation capacity the smaller the amplitudes of vibration. Methods of increasing the energy dissipation capacity are very effective in reducing the amplitude of vibration. Many different methods of increasing damping have been utilized and many others have been proposed. A Passive control system does not require an external power source. Passive control devices impart forces that are developed in response to the motion of the structure. The energy in a passively controlled structural system, including the passive devices cannot be increased by by passive control devices. Methods of increasing the energy dissipation capacity are very effective in reducing the amplitudes of vibration. Many different methods of increasing damping have been utilized and many others have been proposed.

Passive energy dissipation systems encompass a range of materials and devices for enhancing, damping, stiffness and strength and can be used both for natural hazard migration and for rehabilitation of aging or deficient structures. This may be achieved either by conversion of kinetic energy to heat or by transferring energy among vibrating modes.

2.2 Metallic Yield Dampers

One of the effective mechanisms available for the energy dissipation of energy input to a structure from an earthquake is through inelastic deformation of metals. The idea of utilizing added metallic energy dissipaters within the structure to absorb a large portion of seismic energy began with conceptual and experimental work by Kelly et al. (1972) and skinner et al. (1975). Many of the devices use mild steel plates with triangular or hourglass shapes so that the yielding of spread almost uniformly throughout the material.

Other materials such as lead and shape memory alloys have been evaluated. Some particular desirable features of these materials are their stable hysteretic behavior, low cycle fatigue property, long term reliability and relative insensitivity to environment temperature.

2.3 Friction Dampers

Friction provides excellent mechanism for energy dissipation and has been used for many years in automotive brakes to dissipate kinetic energy of motion. In structural engineering wide variety of devices have been proposed and developed, differing in mechanical complexity and sliding materials. In the development of damper it is important to minimize stick slip phenomena to avoid introducing high frequency excitation. Pall device is one of the damper element utilizing the friction principle. The dampers are designed not to slip during wing storms or moderate earthquakes. However under severe loading conditions, the devices slip at a predetermined optimum load before yielding occurs in primary structure members. Sumitomo friction damper, energy dissipating restraint and slotted bolted connection energy dissipater provide good performance and their behavior is not significantly affected by loading amplitude, frequency or even the number of loading cycles. Most friction devices utilize sliding interface consisting f steel on steel, brass on steel or graphite impregnated bronze on stainless steel. Composition of the interface is of great importance for insuring longevity of the operation of the devices.

A combination mechanism which incorporates a friction damping device for control of structural damage due to severe earthquake motion and viscoelastic damping devices for control of low level excitation such as wind force or mild ground moments as been a subject of recent investigations.

2.4 Viscoelastic Dampers

The metallic and frictional devices described are primarily intent for seismic applications. On the other hand there is a class of viscoelastic solid materials that can be used to dissipate energy at all deformation levels. Therefore viscoelastic dampers can find application in both wind and seismic protection. The application of viscoelastic materials to vibration control dates back to 1950's when they were used to aircrafts as a means of controlling vibration induced fatigue in airframes. Their application I civil engineering structures appears to began in 1969 when approximately 10,000 viscoelastic dampers were installed in each of the twin towers of the World Trade Center in New York to reduce Wind induced vibrations. Viscoelastic materials used in Civil Engineering are typical copolymers or glassy substances. A typical Viscoelastic material is shown in Fig. 2. It consists of viscoelastic layer bonded with steel plates and hysteretic loops. The behavior of Viscoelastic materials under dynamic loading depends on vibration frequency, strain and ambient temperature.

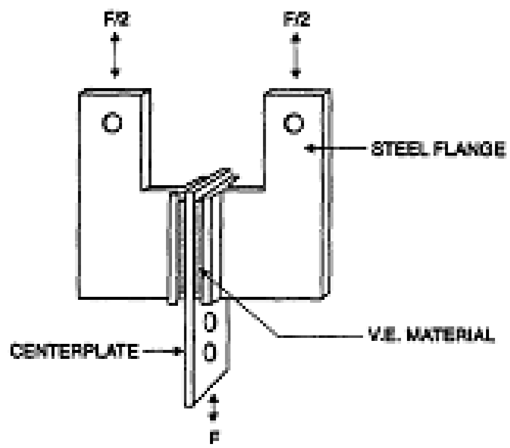

Figure 1: ViscoElastic Damper

2.5 Viscous Fluid Dampers

Fluids can also be used to dissipate energy and numerous device configurations and materials have been proposed one class involves the use of cylindrical piston immersed in a viscoelastic fluid. Such a system has been studied both experimentally and analytically. Another proposed device involves the concept of viscous damping wall using a viscoelastic fluid.

Viscous fluid dampers widely used in aerospace and military applications, have been recently adapted in Structural applications. Characteristics of these devices which are primary interest of structural application are the linear viscous response achieved over a broad frequency range, insensitivity to temperature and compactness in comparison to stroke and output force. The viscous nature of the device is obtained through the use of specially configured orifices and is responsible for generating damper forces that are out of phase with displacement. Viscous Fluid dampers generally consist of a piston in a damper housing filled with a compound of silicon or oil. A typical damper is shown in Fig. 3. It dissipates energy through movement of the piston in the highly viscous fluid.

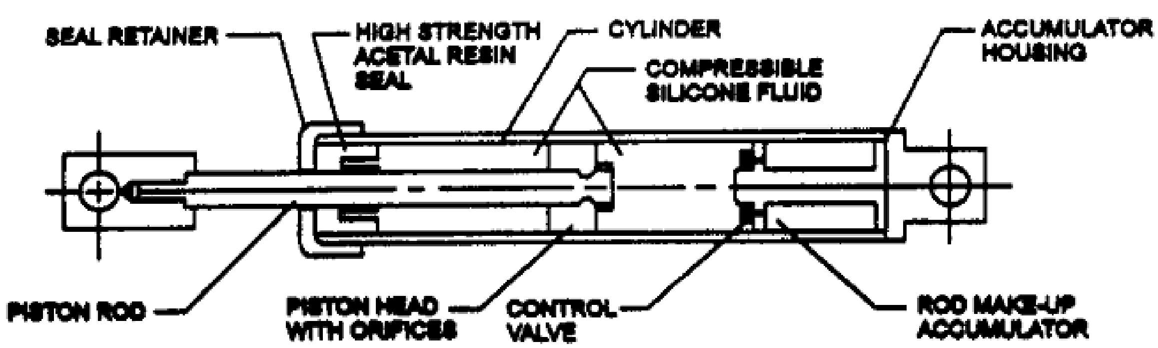

Figure 2: Viscous Fluid Dmaper

2.6 Tuned Mass Dampers

It consist of secondary mass with properly tuned spring and damping elements providing a frequency dependent hysteresis that increase damping in the primary structure. The success of such a system in reducing the wind excited structural vibrations is now well established. Numerical and experimental results show tat the effectiveness of TMD's on reducing the response of the same structure during different earthquakes or different structures during the same earthquake s significantly different; some case give good performance and some have little or no effect. This implies that that there is a dependency of attained reduction in response on the characteristics of the ground motion that excites the structure. The response reduction is large for resonant ground motions and diminishes as the dominant frequency of the ground motion gets further away from the structure's natural frequency to which the TMD is tuned. Also, TMDs are of limited effectiveness under pulse like seismic loading. To overcome the frequency related limitations of TMDs more then one TMD in a given structure, each tuned to a different dominant frequency can be used.

While basic principles of TMDs on reducing structural response have been weel established, optimal TND configurations may be quite different for different structures, even for similar structure.

A number of practical considerations must be observed in the engineering design of a TMD system, First and foremost is the amount of added mass that can be practically placed on the top of the building is another important design parameter. Anther major engineering technique associated with a sliding mass arrangement is to provide a low friction bearing surface so that the mass can respond to the building movement at low levels of excitation. This becomes more critical when TMD functions are used as an additional damper to improve occupant comfort. Use of TMD in a ase isolated system has the advantage o absorbing seismic energy without contaminating the isolating effect, and the relative base displacement of the system may be reduced significantly. A number of TMDs have been installed in tall buildings, bridges and smoke stacks for response control against primarily wind induced external loads.

2.7 Tuned Liquid Dampers

Similar to the concept of TMD, the tuned liquid damper (TLD) and tuned liquid column damper (TLCD) impart indirect damping to the system and thus improve structural performance. A TLD absorbs structural energy by means of viscous actions of the fluid and wave breaking. In TLCD energy is dissipated by passage of liquid through an orifice with inherent head loss characteristics. TLDs have found practical applications in the area of structural control of wind induced vibrations. TLDs operate on same concept as TLDs; however some drawbacks of TMDs are not present in TLDs. Due to simple physical concepts on which the restoring force is provided in TLDs, no activation mechanism is required. Therefore the maintenance cost is minimized. The mechanism activating a TMD must be set to a certain threshold level of excitation, while TLD systems are at all times active.

Mechanical theory involved in a describing the motion of a fluid in a container may be quite complicated, the hardware requirements are sufficiently simple that a minimum of installation is required. A damper in general consists of a polypropylene tank with several shallow layers of water. Maintenance of system is practically inexistent. Due to simplicity of installation they may be used in existing buildings.

2.8 Base Isolation

Base isolation is considered to be an aseimic approach in which the building is protected from the hazard of Earthquake forces by mechanism which reduces the transmission of horizontal acceleration into the structure. The main concept of Base isolation is to reduce the fundamental frequency of structural vibration to a value lower then the predominant energy contain frequencies of earthquake ground motions. By using Base isolation technique the structure is essentially uncoupled from the ground motion during earthquakes.

The first mode of isolated structure involves deformations only in the isolation system; the structure above remains almost rigid. Thus the high energy of the ground motion at the higher mode frequencies are deflected. In this way isolation becomes an attractive approach where protection of expensive sensitive equipment and internal nonstructural components is needed. This action of the isolation system is independent of damping, although some damping is beneficial to suppress resonance due to long period motion at the frequency of the isolation system. However beyond a optimum level of damping high acceleration in the superstructure may be caused, but displacement remains controlled.

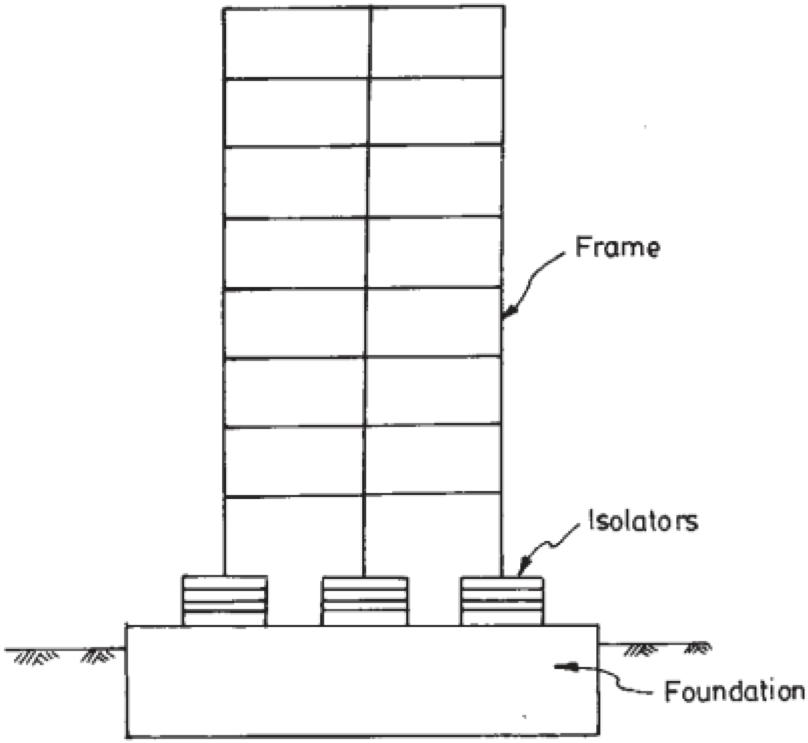

Figure 3 : Base Isolation

Although the concept of base isolation has been used for aseismic design of many practical buildings it is not gained wide popularity. The main reason for this are:

(1) Building code provision for the design of base isolated buildings are still in developing stage.
(2) The design and analysis of such buildings require addition effort and attention.
(3) The total construction cost is likely to increase.

(a)Laminated Rubber Bearing

The laminated Rubber bearing (LBR) base isolation system is the most common system. The basic components are steel and rubber plates built in alternate layers. The dominant feature of LBR system is a parallel action of linear spring and damping. Generally an LBR exhibits high damping capacity, horizontal flexibility and high vertical stiffness. The LBR system is characterized by two parameters: natural frequency and damping constant. The damping constant of the system varies considerably with strain of the bearing.

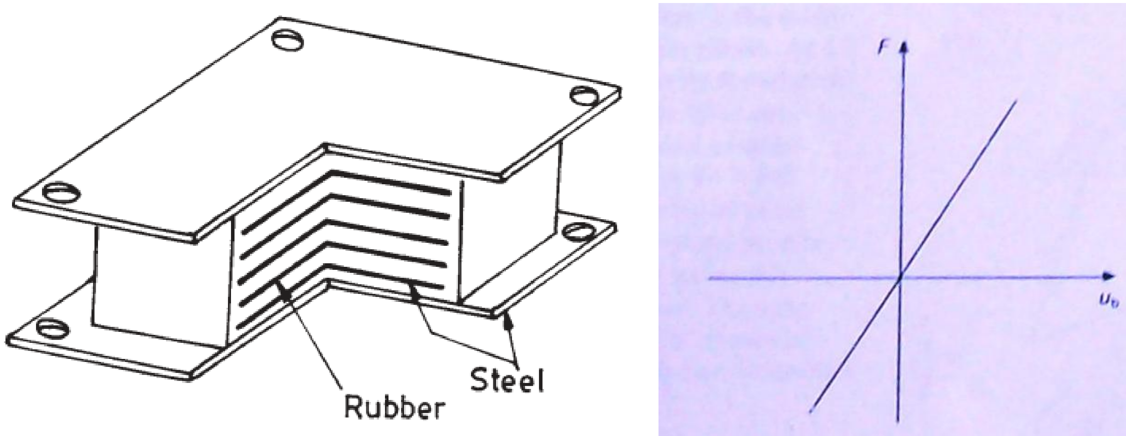

Figure 4 : Laminated Rubber Bearing (a) Section and elements (b) force- deformation behavior

(b)New Zealand bearing System

The bearing in the New Zealand system(NZ- bearing system) are similar to laminated Rubber bearings, but the central Lead core is used to provide additional means of energy dissipation. The energy absorbing capacity of lead core reduces the lateral displacement of the isolator. The system behaves essentially as an hysteretic damper device. The main disadvantage of this type of bearing is that damage to the core after a strong earthquake cannot be detected from the outside. The force displacement characteristics if the hysteretic damper can be modeled exactly by a set of coupled nonlinear differential equations.

Typical hysteresis loop, such as elasto-plastic, rigid friction, bi-linear and smooth hysteretic are generated by attributing appropriate values to the variables of the differential equation.

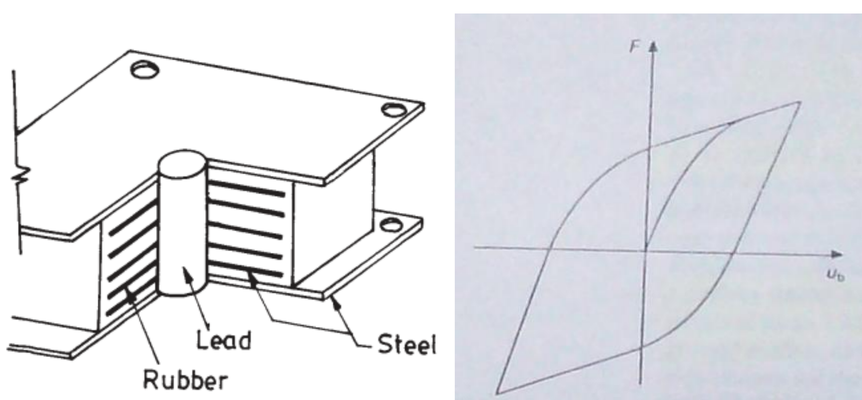

Figure 5: Lead Rubber Bearing (New Zealand system): (a) section and elements (b) force-deformation behavior

(c)Pure friction System

A Pure friction (P-F) type base isolator is based essentially on the mechanism of sliding friction. The horizontal frictional force offers resistance to motion and dissipate energy. The use of layer of sand or a roller in the foundation of the building is the simplest example of the P-F base isolator. The advantages of frictional isolation as compared with conventional rubber bearing systems are as follows.

(1) A frictional base isolation system is effective for a wide range of frequency input.
(2) As the frictional force is developed at the base, it is proportional to the mass of the structure, and centre of mass and centre of resistance of the sliding support coincide. As a result the tensional effect produced by the asymmetric buildings is diminished.

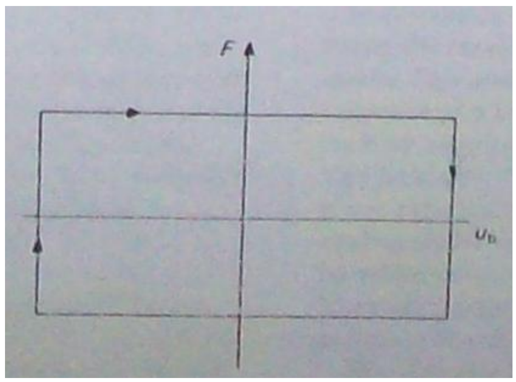

Figure 6: Pure friction system: force deformation behavior

(d)Resilient friction base isolation system

The resilient friction base isolation (R-FBI) system was proposed recently. The base isolator consists of concentric layers of Teflon- coated plates that are in friction contact with one another, and it contains a a central core of rubber. It combines the beneficial effect of friction damping with that of resiliency of rubber. The rubber core distributes the sliding displacement and velocity along the height of R-FBI bearing. The system provides isolation through the parallel action of friction, damping and restoring force and characterized by natural frequency , damping constant and coefficient of friction.

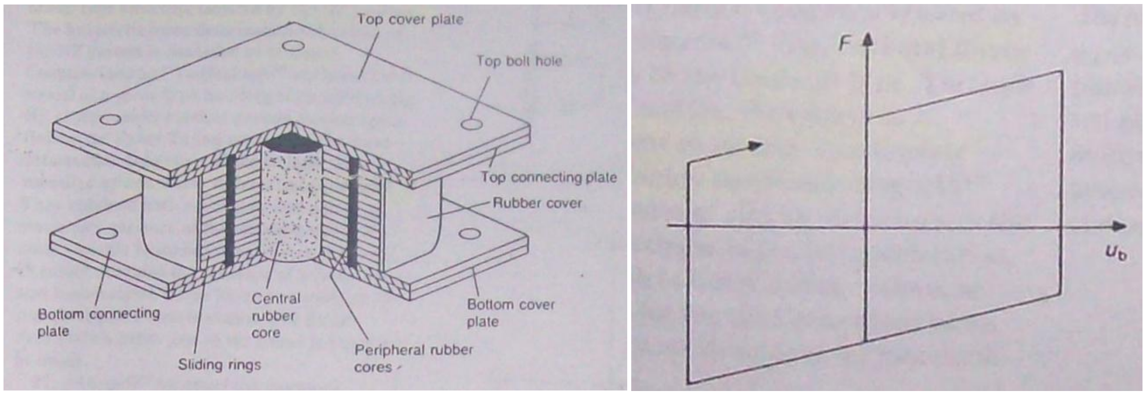

Figure 7: Resilient friction base isolator system : (a) section and elements (b) force deformation behavior

(e) Electric de France system

An important friction type base isolator is a system developed under the auspices of Electric de France (EDF). This system is standardized for nuclear power plants in regions of high seismicity and is constructed by French company Framatome. The main isolator of the EDF consists of Laminated (steel reinforced) Neoprene pad toped by a lead bronze plate which is in frictional contact with steel plate anchored to the base raft of the structure. So the cross-section of the EDF system is almost the same as the LRB system.

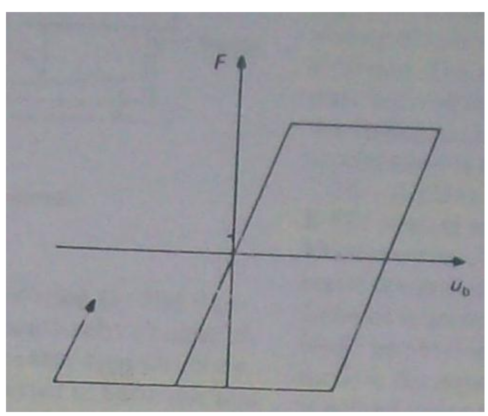

Figure 8: Electric de France systems (a) force deformation behavior

(f) Sliding resilient friction System

The Sliding resilient friction(S-RF) base isolator combines the desirable features of the EDF and the R-FBI systems, The upper surface of the R-FBI system in the modified design is replaced by friction plates. AS a result the structure can slide on its foundation in a manner similar to that of the EDF base isolation system. For a low level of seismic excitation, the system behaves as an R-FBI system.

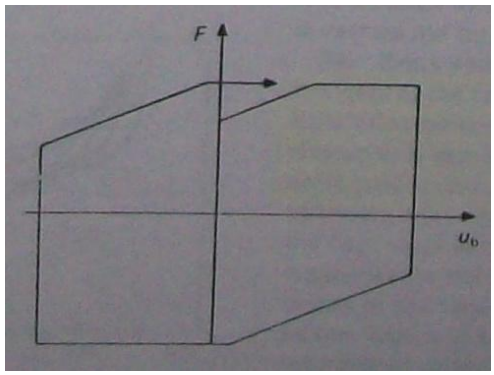

Figure 9 Sliding resilient friction system (a) force- deformation behavior

(g) Friction Pendulum System

The friction pendulum system (FPS) an innovative seismic isolation system, offers an improvement in strength, versatility and ease of installation. It is based on the well known engineering principles of pendulum motion and is constructed of materials with demonstrated longevity and resistance to environmental deterioration. The structure supported by the FPS responds to earthquake motions with small amplitude pendulum motions with small amplitude pendulum motion. The friction damping absorbs the earthquake's energy.

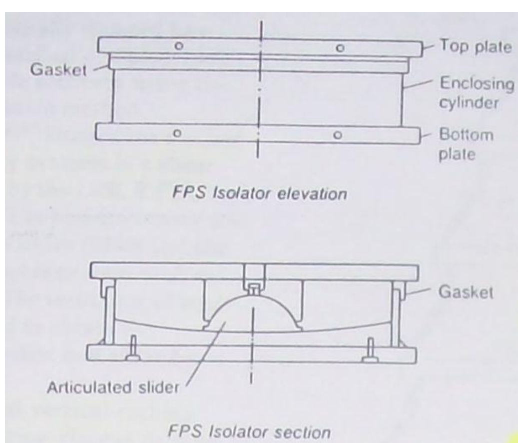

Figure 10: Friction Pendulum System

(h)High damping rubber bearing

The high damping rubber bearings were made form a blend of filled natural rubber. The compound, a high damping elastomer is called KL301 and is manufactured by the Bridgestone Corporation Ltd, Japan. KL301 has a shear modulus of about 4300 kPa at very small strains. Which decrease to 650 kPa or 50% strain, to 430 kPa at 100% strain, and to 340 kPa at 150% strain. The bearing consists of 20 layers of 2-2 mm thick rubber at 176 mm dia, nineteen 1 mm steel shims, and 12 mm top and bottom plates.

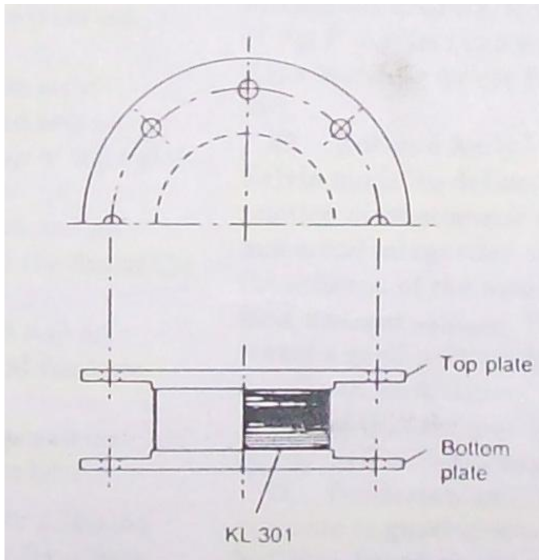

Figure 11: High Damping Rubber Bearing

2.9 Other Energy Dissipaters

To reduce aerodynamic vibrations of bridge cables, a method of vibration suspension was proposed in which the protection tube surface of the cables is cut as V-stripes and U- Stripes. The result of wind tunnel testing show that the Reynolds's no of the cable configured by V-stripes or U-stripes increase appreciably and aerodynamic vibrations could be significantly reduced but means of this technique.

When the mass ratio and stiffness ratio between eh structures are optimized, the response of both structures are optimized, the response of both structures can be simultaneously reduced by using an optimum connecting damper.

Chapter 3

Equation of Motion

3.1 Single Degree of freedom system

The number of independent displacements required to define the displaced position of all the masses relative to their original position is called the number of degrees of freedom (DOFs) for the dynamic system. More DOFs are typically necessary to define the stiffness properties of a structure compared to the DOFs necessary for dynamic analysis. Consider the one storey frame in figure constrained to move only in one direction of the excitation. The static problem had to be formulated with three DOFs – lateral displacement and two joint rotations – to determine the lateral stiffness of the frame. In contract, the structure has only one DOF- lateral displacement- for dynamic analysis if it is idealized with mass concentrated at one location, typically the roof level. Thus we call this a single –degree of freedom (SDF) system.

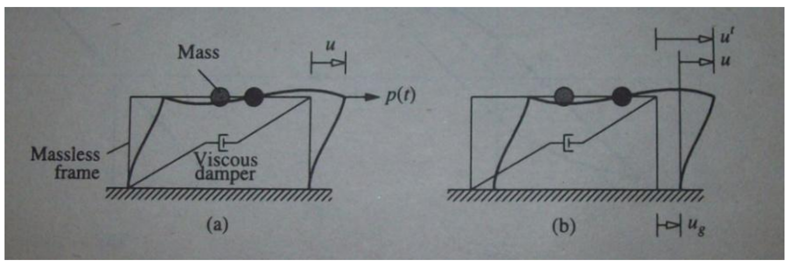

Figure 12 : Single degree of freedom system : (a) applied force p(t) ; (b) earthquake induced ground motion

Two types of dynamic excitation will be considered: (1) external force p(t) in the lateral direction and (2) earthquake induced ground motion $u_g(t)$. In both cases u denoted the relative displacement between the mass and the base of the structure.

3.2 Force Displacement Relation

The system shown in figure with no dynamic excitation subjected to an externally applied static force fs along the DOF u. The internal force resisting the displacement u is equal and opposite of the external force fs. This force- displacement relation would be linear at small dimensions but would be non linear at larger deformations.

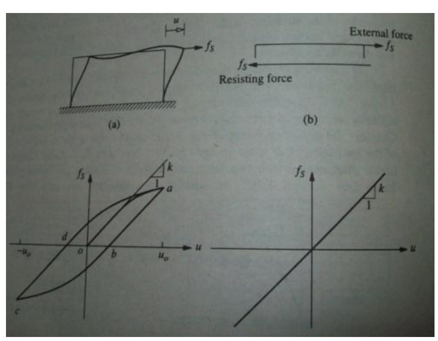

Figure 13 : Force Displacement Relation

3.3 Linear Elastic Systems

For linear systems the relationship between the lateral force fs and resulting deformations u is linear, that is,

$$Fs = ku \qquad \text{(eq 3.1)}$$

Where *k* is the lateral stiffness of the system: its units are force/length. Implicit in equation is the assumption that the linear *fs-u* relationship determined for small deformations of the structure is also valid for larger deformations. Because the resisting force is single valued function of u, the system is elastic; hence we use the term linearly elastic system.

Consider the frame in figure with bay length L, height h, elastic modulus E, and second moment of the cross sectional area about the axis of bending = I_b and I_c for the beam and columns, the columns are clamped at base. The lateral stiffness of the frame can be readiely be determined for the two extreme cases: If the beam is rigid [i.e. flexural rigidity $Ei_b = \infty$

$$k = \sum_{columns} \frac{12\, E\, I_c}{h^3} = \frac{24\, E\, I_c}{h^3}$$

(Eq 3.2)

On the other hand , for a beam with no stiffness [i.e. $Ei_b = 0$]

$$k = \sum_{columns} \frac{3\, E\, I_c}{h^3} = \frac{6\, E\, I_c}{h^3}$$

(Eq. 3.3)

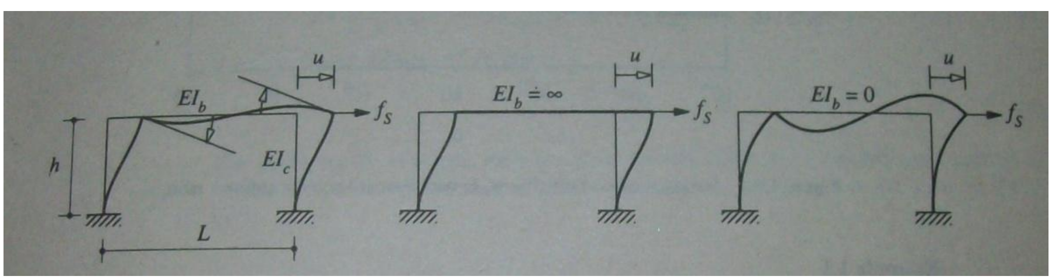

Figure 14 : Linear Elastic System

3.4 Damping Force

The process by which free vibration steadily diminishes in amplitude is called damping. In damping the energy of vibrating system dissipated by various mechanisms and often more than one mechanism may be present at same time. In Simple “clean” system such as laboratory models most of the energy dissipation presumably arises from the thermal effect of repeated elastic straining of the material and from the internal friction when a solid is deformed. In actual structures, many other mechanisms contribute to energy dissipation. In a vibrating building these include friction at steel connections, opening and closing of micro cracks in concrete, friction between structure itself and nonstructural elements such as partition walls. It seems impossible to identify pr describe mathematically each of these energy dissipating mechanisms in an actual building.

Damping in actual structure represented in a highly idealized manner. For many purposes the actual damping in a SDF structure can be idealized satisfactorily by linear viscous damper or dashpot. The damping coefficient is selected so that the vibrating energy is dissipates is equivalent to energy dissipated in all the damping mechanisms , combined present in the actual structure. This idealization is therefore called equvivalent viscous damping.

Figure 15 shows a linear viscous damper subjected to a force f_D along the DOF u. The internal force in the damper is equal and opposite to the external forces f_D. As shown in figure the damping force f_D is related to the velocity $\dot{u}$ across the linear viscous damper by

$$f_D = c\dot{u} \qquad \text{(Eq 3.5)}$$

Where c is the viscous damping coefficient it has units of force x time/length.

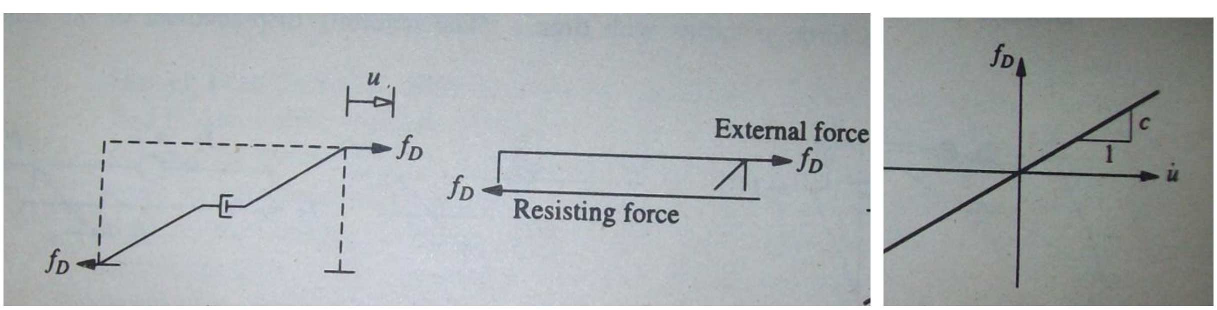

Figure 15 : Damping Force

Unlike the structure, the damping coefficient cannot be calculated from the dimensions of the structure and the sizes of the structural elements . This is not feasible to identify all the damping mechanisms that dissipate vibrational energy of actual structures. Thus vibration experiments on actual structure provide the data for the data for evaluating the damping coefficient.

3.5 Equation of Motion: External Force

Figure shows the idealized one storey frame subjected to an externally applied dynamic force p(t) in the direction of the DOF u . The notation indicates that the force p varies with time t. The resulting displacement of the mass also varies with time; it is denoted by u(t).

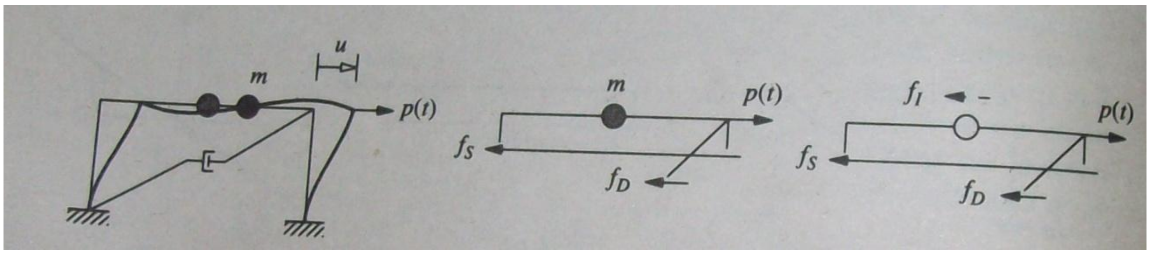

Figure 16 : Equation of motion

Using Newton's Second law of motion

The forces acted on the mass at some instant of time are shown in figure. These including the external forces p(t), the elastic resisting force fs and the damping force f_D. The external force is taken to be positive in the direction of the x-axis, the displacement u(t), velocity˙ u̇(t) and acceleration ü(t) are also positive in the direction of x-axis. The elastic and damping forces are shown in acting in the opposite direction because they are internal force that resists the deformation and velocity.

The resultant force along the x-axis is $p - f_s - f_d$ and Newton's second law of motion gives

$$p - f_s - f_d = m\,\ddot{u} \text{ or } m\ddot{u} + f_D + f_S = p(t) \qquad \text{(Eq 3.6)}$$

After substituting this equation becomes

$$M\ddot{u} + c\dot{u} + ku = p(t) \qquad \text{(Eq 3.7)}$$

This is the equation of motion governing the deformation or displacement u(t) of the idealized structure of figure assuming to be linearly elastic subjected to an exernal dynamic force p(t) . The unit of mass is force/ acceleration

This derivation can be readily extended to inelastic systems. Equation is still valid and al that needs to be done is to replace Equation restricted to linear systems by equation valid for inelastic systems. For such a systems, therefore the equation of motion is

$$M\ddot{u} + c\dot{u} + f_S(u,\dot{u}) = p(t) \qquad \text{(Eq 3.8)}$$

Dynamic Equilibrium

D' Alembert's principle based on the notion of a frictious inertia force, a force equal to the product of mass times its acceleration and acting in a direction opposite to the acceleration. It states that with inertia forces included, a system is in equilibrium at each time instant. Thus a free body diagram of a moving mass can be drawn and principles of statics can be used to develop the equation of motion.

3. 6 Stiffness, Damping and Mass Components

Under the action of external force p(t) the state of the system is described by displacement u(t) , velocity $\dot{u}$(t) and acceleration $\ddot{u}$(t). Now visualize system as the combination of three pure component: the frame with its damping property with no stiffness or mass, the mass component : the roof mass without the stiffness or damping of the frame. The external force f_S on the stiffness component is related to the displacement u , if the system is linearly elastic the external force f_D on the damping component is related to the velocity $\dot{u}$ by equation and the external force f_I on the mass component is related to the acceleration by $f_I = m\ddot{u}$. The external force applied to the complete system may therefore be visualized as distributed among the three components of the structure and fs +fD + f_I must be equal to the applied force p(t).

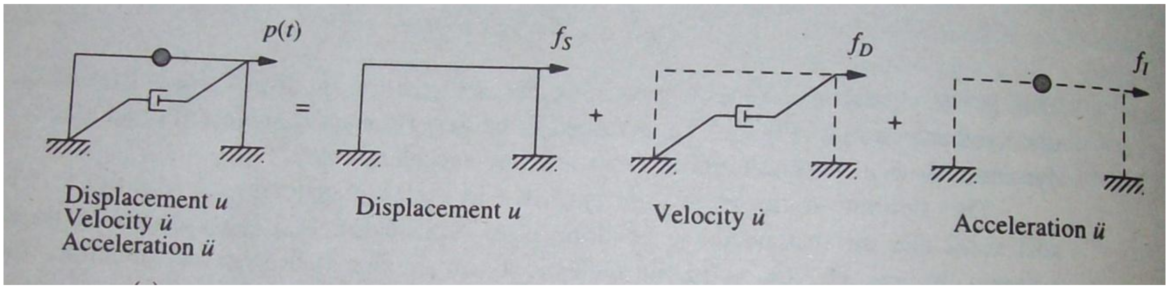

Figure 17 : (a) System , (b) Stiffness Component ,(c) damping component , (d) mass component

3. 7 Equation of Motion: Earthquake Equation

In the Earthquake prone regions the principal problem of structural dynamics that concern structural engineers id the behavior of structures subjected to Earthquake induced motion of the base of the structure. The displacement of ground is denoted by u_g, the total displacement of mass by u^t and relative displacement between the mass and ground by u. At each instant of time these displacements are related by

$$U^t(t) = u(t) + u_g(t) \qquad \text{(Eq 3.9)}$$

Both u^t and u_g refer to the internal frame of reference and positive directions coincide.

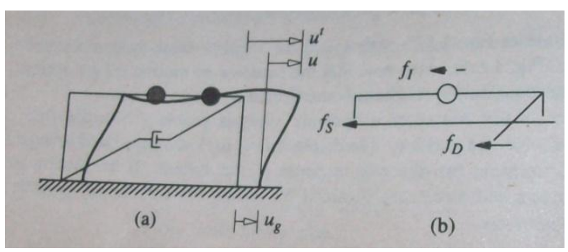

Figure: 18 : Equation of motion : Earthquake Motion

The equation of motion for the idealized one storey system of figure 18 subjected to earthquake excitation can be derived by any one of the approaches as mentioned earlier. From the free body diagram the equation of dynamic equilibrium is

$$f_I + f_D + f_S = 0 \qquad \text{(Eq 3.10)}$$

Only the relative motion u between the mass and base due to structural deformation produces only elastic and damping forces. Thus for linear system f_I is related to acceleration $\ddot{u}^t$ of the mass by

Substituting all the values in the Equation

$$m\ddot{u} + c\dot{u} + ku = - m\ddot{u}_g(t) \qquad \text{(Eq 3.11)}$$

This is the equation of motion governing the relative displacement or deformation u(t) of linear structure subjected to ground acceleration $\ddot{u}_g(t)$. These Equation shows that the equation of motion for the structure subjected to two separate excitations- ground acceleration $m\ddot{u}_g(t)$ and external force = $-m\ddot{u}_g(t)$- are one and the same. Thus the relative displacement or deformation u(t) of the srucutre due to ground acceleration $m\ddot{u}_g(t)$ will be identical to the displacement u(t) of the structure if its base were stationary and if it is subjected to an external force = -m $m\ddot{u}_g(t)$. As shown in figure 19 the ground motion therefore be replaced by *effective earthquake force*:

$$P_{eff}(t) = - m\ddot{u}_g(t) \qquad \text{(Eq 3.12)}$$

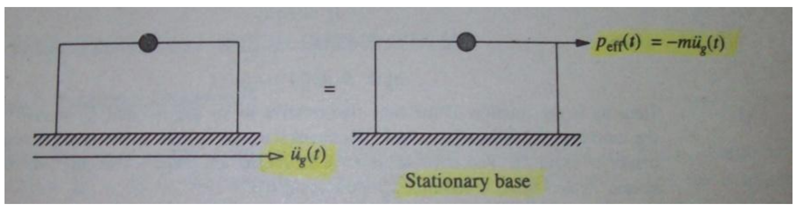

Figure 19: Effective earthquake force: horizontal ground motion

Chapter 4

Coding in MATLAB

4.1 Problem Statement:

For a linearly elastic Frame find out the Earthquake response, with and without Viscoelastic Dampers and compare the results. This frame has 3 bays @ 5 m and height of frame is 5m. Compute the displacement of the roof using Equation of motion for Earthquake excitation for every 0.02 sec. Use the acceleration data of El Centro Earthquake.

Solution

The frame is single degree of freedom.

Bay length	=	5m
Height of Frame	=	5m
Dimension of Column	=	500 mm X 500 mm
Dimension of beam	=	800 mm X 500 mm
Elasticity of modulus	=	2 X 10^5 N/mm^2
Mass of frame	=	300 X 10^3 N

From the Equation

$$k = \sum_{columns} \frac{3\ E\ I_c}{h^3} = \frac{6\ E\ I_c}{h^3}$$

k	=	20 N/mm
c (for Viscoelactic damper)	=	15 N-sec/mm

Equation of motion for Earthquake using VE dampers

$$m\ddot{u} + c\dot{u} + ku = - m\ddot{u}_g(t)$$

By putting all the values we get a second order differential equation. Value of $\ddot{u}_g(t)$ is given by the Earthquake data for every 0.02 sec. After solving the Equation for t = 0.02sec(say) displacement at t = 0.02 sec will become initial condition for t = 0.04 sec and value of $\ddot{u}_g(t = 0.04)$ is taken and differential equation is again solved.

We have a matrix of [1 X1600] of Earthquake acceleration and after solving we have a matrix of [1 X 1600] . Solution is plotted in form of graph.

4.2 Coding in MATLAB

Coding for frame under Earthquake with damper

```
for i = 1:1:1559

g = [ 0.00630  0.00364  0.00099  0.00428  0.00758  0.01087  0.00682  0.00277  -0.00128  0.00368
0.00864  0.01360  0.00727  0.00094  0.00420  0.00221  0.00021  0.00444  0.00867  0.01290
0.01713  -0.00343  -0.02400  -0.00992  0.00416  0.00528  0.01653  0.02779  0.03904  0.02449
0.00995  0.00961  0.00926  0.00892  -0.00486  -0.01864  -0.03242  -0.03365  -0.05723  -0.04534
-0.03346  -0.03201  -0.03056  -0.02911  -0.02766  -0.04116  -0.05466  -0.06816  -0.08166  -0.06846
-0.05527  -0.04208  -0.04259  -0.04311  -0.02428  -0.00545  0.01338  0.03221  0.05104  0.06987
0.08870  0.04524  0.00179  -0.04167  -0.08513  -0.12858  -0.17204  -0.12908  -0.08613  -0.08902
-0.09192  -0.09482  -0.09324  -0.09166  -0.09478  -0.09789  -0.12902  -0.07652  -0.02401  0.02849
0.08099  0.13350  0.18600  0.23850  0.21993  0.20135  0.18277  0.16420  0.14562  0.16143
0.17725  0.13215  0.08705  0.04196  -0.00314  -0.04824  -0.09334  -0.13843  -0.18353  -0.22863
-0.27372  -0.31882  -0.25024  -0.18166  -0.11309  -0.04451  0.02407  0.09265  0.16123  0.22981
0.29839  0.23197  0.16554  0.09912  0.03270  -0.03372  -0.10014  -0.16656  -0.23299  -0.29941
-0.00421  0.29099  0.22380  0.15662  0.08943  0.02224  -0.04495  0.01834  0.08163  0.14491
0.20820  0.18973  0.17125  0.13759  0.10393  0.07027  0.03661  0.00295  -0.03071  -0.00561
0.01948  0.04458  0.06468  0.08478  0.10487  0.05895  0.01303  -0.03289  -0.07882  -0.03556
0.00771  0.05097  0.01013  -0.03071  -0.07156  -0.11240  -0.15324  -0.11314  -0.07304  -0.03294
0.00715  -0.06350  -0.13415  -0.20480  -0.12482  -0.04485  0.03513  0.11510  0.19508  0.12301
0.05094  -0.02113  -0.09320  -0.02663  0.03995  0.10653  0.17311  0.11283  0.05255  -0.00772
0.01064  0.02900  0.04737  0.06573  0.02021  -0.02530  -0.07081  -0.04107  -0.01133  0.00288
0.01709  0.03131  -0.02278  -0.07686  -0.13095  -0.18504  -0.14347  -0.10190  -0.06034  -0.01877
0.02280  -0.00996  -0.04272  -0.02147  -0.00021  0.02104  -0.01459  -0.05022  -0.08585  -0.12148
-0.15711  -0.19274  -0.22837  -0.18145  -0.13453  -0.08761  -0.04069  0.00623  0.05316  0.10008
0.14700  0.09754  0.04808  -0.00138  0.05141  0.10420  0.15699  0.20979  0.26258  0.16996
0.07734  -0.01527  -0.10789  -0.20051  -0.06786  0.06479  0.01671  -0.03137  -0.07945  -0.12753
```

-0.17561	-0.22369	-0.27177	-0.15851	-0.04525	0.06802	0.18128	0.14464	0.10800	0.07137
0.03473	0.09666	0.15860	0.22053	0.18296	0.14538	0.10780	0.07023	0.03265	0.06649
0.10033	0.13417	0.10337	0.07257	0.04177	0.01097	-0.01983	0.04438	0.10860	0.17281
0.10416	0.03551	-0.03315	-0.10180	-0.07262	-0.04344	-0.01426	0.01492	-0.02025	-0.05543
-0.09060	-0.12578	-0.16095	-0.19613	-0.14784	-0.09955	-0.05127	-0.00298	-0.01952	-0.03605
-0.05259	-0.04182	-0.03106	-0.02903	-0.02699	0.02515	0.01770	0.02213	0.02656	0.00419
-0.01819	-0.04057	-0.06294	-0.02417	0.01460	0.05337	0.02428	-0.00480	-0.03389	-0.00557
0.02274	0.00679	-0.00915	-0.02509	-0.04103	-0.05698	-0.01826	0.02046	0.00454	-0.01138
-0.00215	0.00708	0.00496	0.00285	0.00074	-0.00534	-0.01141	0.00361	0.01863	0.03365
0.04867	0.03040	0.01213	-0.00614	-0.02441	0.01375	0.01099	0.00823	0.00547	0.00812
0.01077	-0.00692	-0.02461	-0.04230	-0.05999	-0.07768	-0.09538	-0.06209	-0.02880	0.00448
0.03777	0.01773	-0.00231	-0.02235	0.01791	0.05816	0.03738	0.01660	-0.00418	-0.02496
-0.04574	-0.02071	0.00432	0.02935	0.01526	0.01806	0.02086	0.00793	-0.00501	-0.01795
-0.03089	-0.01841	-0.00593	0.00655	-0.02519	-0.05693	-0.04045	-0.02398	-0.00750	0.00897
0.00384	-0.00129	-0.00642	-0.01156	-0.02619	-0.04082	-0.05545	-0.04366	-0.03188	-0.06964
-0.05634	-0.04303	-0.02972	-0.01642	-0.00311	0.01020	0.02350	0.03681	0.05011	0.02436
-0.00139	-0.02714	-0.00309	0.02096	0.04501	0.06906	0.05773	0.04640	0.03507	0.03357
0.03207	0.03057	0.03250	0.03444	0.03637	0.01348	-0.00942	-0.03231	-0.02997	-0.03095
-0.03192	-0.02588	-0.01984	-0.01379	-0.00775	-0.01449	-0.02123	0.01523	0.05170	0.08816
0.12463	0.16109	0.12987	0.09864	0.06741	0.03618	0.00495	0.00420	0.00345	0.00269
-0.05922	-0.12112	-0.18303	-0.12043	-0.05782	0.00479	0.06740	0.13001	0.08373	0.03745
0.06979	0.10213	-0.03517	-0.17247	-0.13763	-0.10278	-0.06794	-0.03310	-0.03647	-0.03984
-0.00517	0.02950	0.06417	0.09883	0.13350	0.05924	-0.01503	-0.08929	-0.16355	-0.06096
0.04164	0.01551	-0.01061	-0.03674	-0.06287	-0.08899	-0.05430	-0.01961	0.01508	0.04977
0.08446	0.05023	0.01600	-0.01823	-0.05246	-0.08669	-0.06769	-0.04870	-0.02970	-0.01071
0.00829	-0.00314	0.02966	0.06246	-0.00234	-0.06714	-0.04051	-0.01388	0.01274	0.00805
0.03024	0.05243	0.02351	-0.00541	-0.03432	-0.06324	-0.09215	-0.12107	-0.08450	-0.04794
-0.01137	0.02520	0.06177	0.04028	0.01880	0.04456	0.07032	0.09608	0.12184	0.06350
0.00517	-0.05317	-0.03124	-0.00930	0.01263	0.03457	0.03283	0.03109	0.02935	0.04511
0.06087	0.07663	0.09239	0.05742	0.02245	-0.01252	0.00680	0.02611	0.04543	0.01571
-0.01402	-0.04374	-0.07347	-0.03990	-0.00633	0.02724	0.06080	0.03669	0.01258	-0.01153
-0.03564	-0.00677	0.02210	0.05098	0.07985	0.06915	0.05845	0.04775	0.03706	0.02636
0.05822	0.09009	0.12196	0.10069	0.07943	0.05816	0.03689	0.01563	-0.00564	-0.02690
-0.04817	-0.06944	-0.09070	-0.11197	-0.11521	-0.11846	-0.12170	-0.12494	-0.16500	-0.20505
-0.15713	-0.10921	-0.06129	-0.01337	0.03455	0.08247	0.07576	0.06906	0.06236	0.08735
0.11235	0.13734	0.12175	0.10616	0.09057	0.07498	0.08011	0.08524	0.09037	0.06208
0.03378	0.00549	-0.02281	-0.05444	-0.04030	-0.02615	-0.01201	-0.02028	-0.02855	-0.06243
-0.03524	-0.00805	-0.04948	-0.03643	-0.02337	-0.03368	-0.01879	-0.00389	0.01100	0.02589
0.01446	0.00303	-0.00840	0.00463	0.01766	0.03069	0.04372	0.02165	-0.00042	-0.02249
-0.04456	-0.03638	-0.02819	-0.02001	-0.01182	-0.02445	-0.03707	-0.04969	-0.05882	-0.06795
-0.07707	-0.08620	-0.09533	-0.06276	-0.03018	0.00239	0.03496	0.04399	0.05301	0.03176
0.01051	-0.01073	-0.03198	-0.05323	0.00186	0.05696	0.01985	-0.01726	-0.05438	-0.01204

0.03031	0.07265	0.11499	0.07237	0.02975	-0.01288	0.01212	0.03711	0.03517	0.03323
0.01853	0.00383	0.00342	-0.02181	-0.04704	-0.07227	-0.09750	-0.12273	-0.08317	-0.04362
-0.00407	0.03549	0.07504	0.11460	0.07769	0.04078	0.00387	0.00284	0.00182	-0.05513
0.04732	0.05223	0.05715	0.06206	0.06698	0.07189	0.02705	-0.01779	-0.06263	-0.10747
-0.15232	-0.12591	-0.09950	-0.07309	-0.04668	-0.02027	0.00614	0.03255	0.00859	-0.01537
-0.03932	-0.06328	-0.03322	-0.00315	0.02691	0.01196	-0.00300	0.00335	0.00970	0.01605
0.02239	0.04215	0.06191	0.08167	0.03477	-0.01212	-0.01309	-0.01407	-0.05274	-0.02544
0.00186	0.02916	0.05646	0.08376	0.01754	-0.04869	-0.02074	0.00722	0.03517	-0.00528
-0.04572	-0.08617	-0.06960	-0.05303	-0.03646	-0.01989	-0.00332	0.01325	0.02982	0.01101
-0.00781	-0.02662	-0.00563	0.01536	0.03635	0.05734	0.03159	0.00584	-0.01992	-0.00201
0.01589	-0.01024	-0.03636	-0.06249	-0.04780	-0.03311	-0.04941	-0.06570	-0.08200	-0.04980
-0.01760	0.01460	0.04680	0.07900	0.04750	0.01600	-0.01550	-0.00102	0.01347	0.02795
0.04244	0.05692	0.03781	0.01870	-0.00041	-0.01952	-0.00427	0.01098	0.02623	0.04148
0.01821	-0.00506	-0.00874	-0.03726	-0.06579	-0.02600	0.01380	0.05359	0.09338	0.05883
0.02429	-0.01026	-0.04480	-0.01083	-0.01869	-0.02655	-0.03441	-0.02503	-0.01564	-0.00626
-0.01009	-0.01392	0.01490	0.04372	0.03463	0.02098	0.00733	-0.00632	-0.01997	0.00767
0.03532	0.03409	0.03287	0.03164	0.02403	0.01642	0.00982	0.00322	-0.00339	0.02202
-0.01941	-0.06085	-0.10228	-0.07847	-0.05466	-0.03084	-0.00703	0.01678	0.01946	0.02214
0.02483	0.01809	-0.00202	-0.02213	-0.00278	0.01656	0.03590	0.05525	0.07459	0.06203
0.04948	0.03692	-0.00145	0.04599	0.04079	0.03558	0.03037	0.03626	0.04215	0.04803
0.05392	0.04947	0.04502	0.04056	0.03611	0.03166	0.00614	-0.01937	-0.04489	-0.07040
-0.09592	-0.07745	-0.05899	-0.04052	-0.02206	-0.00359	0.01487	0.01005	0.00523	0.00041
-0.00441	-0.00923	-0.01189	-0.01523	-0.01856	-0.02190	-0.00983	0.00224	0.01431	0.00335
-0.00760	-0.01856	-0.00737	0.00383	0.01502	0.02622	0.01016	-0.00590	-0.02196	-0.00121
0.01953	0.04027	0.02826	0.01625	0.00424	0.00196	-0.00031	-0.00258	-0.00486	-0.00713
-0.00941	-0.01168	-0.01396	-0.01750	-0.02104	-0.02458	-0.02813	-0.03167	-0.03521	-0.04205
-0.04889	-0.03559	-0.02229	-0.00899	0.00431	0.01762	0.00714	-0.00334	-0.01383	0.01314
0.04011	0.06708	0.04820	0.02932	0.01043	-0.00845	-0.02733	-0.04621	-0.03155	-0.01688
-0.00222	0.01244	0.02683	0.04121	0.05559	0.03253	0.00946	-0.01360	-0.01432	-0.01504
-0.01576	-0.04209	-0.02685	-0.01161	0.00363	0.01887	0.03411	0.03115	0.02819	0.02917
0.03015	0.03113	0.00388	-0.02337	-0.05062	-0.03820	-0.02579	-0.01337	-0.00095	0.01146
0.02388	0.03629	0.01047	-0.01535	-0.04117	-0.06699	-0.05207	-0.03715	-0.02222	-0.00730
0.00762	0.02254	0.03747	0.04001	0.04256	0.04507	0.04759	0.05010	0.04545	0.04080
0.02876	0.01671	0.00467	-0.00738	-0.00116	0.00506	0.01128	0.01750	-0.00211	-0.02173
-0.04135	-0.06096	-0.08058	-0.06995	-0.05931	-0.04868	-0.03805	-0.02557	-0.01310	-0.00063
0.01185	0.02432	0.03680	0.04927	0.02974	0.01021	-0.00932	-0.02884	-0.04837	-0.06790
-0.04862	-0.02934	-0.01006	0.00922	0.02851	0.04779	0.02456	0.00133	-0.02190	-0.04513
-0.06836	-0.04978	-0.03120	-0.01262	0.00596	0.02453	0.04311	0.06169	0.08027	0.09885
0.06452	0.03019	-0.00414	-0.03848	-0.07281	-0.05999	-0.04717	-0.03435	-0.03231	-0.03028
-0.02824	-0.00396	0.02032	0.00313	-0.01406	-0.03124	-0.04843	-0.06562	-0.05132	-0.03702
-0.02272	-0.00843	0.00587	0.02017	0.02698	0.03379	0.04061	0.04742	0.05423	0.03535
0.01647	0.01622	0.01598	0.01574	0.00747	-0.00080	-0.00907	0.00072	0.01051	0.02030

0.03009 0.03989 0.03478 0.02967 0.02457 0.03075 0.03694 0.04313 0.04931 0.05550
0.06168 -0.00526 -0.07220 -0.06336 -0.05451 -0.04566 -0.03681 -0.03678 -0.03675 -0.03672
-0.01765 0.00143 0.02051 0.03958 0.05866 0.03556 0.01245 -0.01066 -0.03376 -0.05687
-0.04502 -0.03317 -0.02131 -0.00946 0.00239 -0.00208 -0.00654 -0.01101 -0.01548 -0.01200
-0.00851 -0.00503 -0.00154 0.00195 0.00051 -0.00092 0.01135 0.02363 0.03590 0.04818
0.06045 0.07273 0.02847 -0.01579 -0.06004 -0.05069 -0.04134 -0.03199 -0.03135 -0.03071
-0.03007 -0.01863 -0.00719 0.00425 0.01570 0.02714 0.03858 0.02975 0.02092 0.02334
0.02576 0.02819 0.03061 0.03304 0.01371 -0.00561 -0.02494 -0.02208 -0.01923 -0.01638
-0.01353 -0.01261 -0.01170 -0.00169 0.00833 0.01834 0.02835 0.03836 0.04838 0.03749
0.02660 0.01571 0.00482 -0.00607 -0.01696 -0.00780 0.00136 0.01052 0.01968 0.02884
-0.00504 -0.03893 -0.02342 -0.00791 0.00759 0.02310 0.00707 -0.00895 -0.02498 -0.04100
-0.05703 -0.02920 -0.00137 0.02645 0.05428 0.03587 0.01746 -0.00096 -0.01937 -0.03778
-0.02281 -0.00784 0.00713 0.02210 0.03707 0.05204 0.06701 0.08198 0.03085 -0.02027
-0.07140 -0.12253 -0.08644 -0.05035 -0.01426 0.02183 0.05792 0.09400 0.13009 0.03611
-0.05787 -0.04802 -0.03817 -0.02832 -0.01846 -0.00861 -0.03652 -0.06444 -0.06169 -0.05894
-0.05618 -0.06073 -0.06528 -0.04628 -0.02728 -0.00829 0.01071 0.02970 0.03138 0.03306
0.03474 0.03642 0.04574 0.05506 0.06439 0.07371 0.08303 0.03605 -0.01092 -0.05790
-0.04696 -0.03602 -0.02508 -0.01414 -0.03561 -0.05708 -0.07855 -0.06304 -0.04753 -0.03203
-0.01652 -0.00102 0.00922 0.01946 0.02970 0.03993 0.05017 0.06041 0.07065 0.08089
-0.00192 -0.08473 -0.07032 -0.05590 -0.04148 -0.05296 -0.06443 -0.07590 -0.08738 -0.09885
-0.06798 -0.03710 -0.00623 0.02465 0.05553 0.08640 0.11728 0.14815 0.08715 0.02615
-0.03485 -0.09584 -0.07100 -0.04616 -0.02132 0.00353 0.02837 0.05321 -0.00469 -0.06258
-0.12048 -0.09960 -0.07872 -0.05784 -0.03696 -0.01608 0.00480 0.02568 0.04656 0.06744
0.08832 0.10920 0.13008 0.10995 0.08982 0.06969 0.04955 0.04006 0.03056 0.02107
0.01158 0.00780 0.00402 0.00024 -0.00354 -0.00732 -0.01110 -0.00780 -0.00450 -0.00120
0.00210 0.00540 -0.00831 -0.02203 -0.03575 -0.04947 -0.06319 -0.05046 -0.03773 -0.02500
-0.01227 0.00046 0.00482 0.00919 0.01355 0.01791 0.02228 0.00883 -0.00462 -0.01807
-0.03152 -0.02276 -0.01401 -0.00526 0.00350 0.01225 0.02101 0.01437 0.00773 0.00110
0.00823 0.01537 0.02251 0.01713 0.01175 0.00637 0.01376 0.02114 0.02852 0.03591
0.04329 0.03458 0.02587 0.01715 0.00844 -0.00027 -0.00898 -0.00126 0.00645 0.01417
0.02039 0.02661 0.03283 0.03905 0.04527 0.03639 0.02750 0.01862 0.00974 0.00086
-0.01333 -0.02752 -0.04171 -0.02812 -0.01453 -0.00094 0.01264 0.02623 0.01690 0.00756
-0.00177 -0.01111 -0.02044 -0.02977 -0.03911 -0.02442 -0.00973 0.00496 0.01965 0.03434
0.02054 0.00674 -0.00706 -0.02086 -0.03466 -0.02663 -0.01860 -0.01057 -0.00254 -0.00063
0.00128 0.00319 0.00510 0.00999 0.01488 0.00791 0.00093 -0.00605 0.00342 0.01288
0.02235 0.03181 0.04128 0.02707 0.01287 -0.00134 -0.01554 -0.02975 -0.04395 -0.03612
-0.02828 -0.02044 -0.01260 -0.00476 0.00307 0.01091 0.00984 0.00876 0.00768 0.00661
0.01234 0.01807 0.02380 0.02953 0.03526 0.02784 0.02042 0.01300 -0.03415 -0.00628
-0.00621 -0.00615 -0.00609 -0.00602 -0.00596 -0.00590 -0.00583 -0.00577 -0.00571 -0.00564
-0.00558 -0.00552 -0.00545 -0.00539 -0.00532 -0.00526 -0.00520 -0.00513 -0.00507 -0.00501
-0.00494 -0.00488 -0.00482 -0.00475 -0.00469 -0.00463 -0.00456 -0.00450 -0.00444 -0.00437
-0.00431 -0.00425 -0.00418 -0.00412 -0.00406 -0.00399 -0.00393 -0.00387 -0.00380 -0.00374

```
-0.00368 -0.00361 -0.00355 -0.00349 -0.00342 -0.00336 -0.00330 -0.00323 -0.00317 -0.00311
-0.00304 -0.00298 -0.00292 -0.00285 -0.00279 -0.00273 -0.00266 -0.00260 -0.00254 -0.00247
-0.00241 -0.00235 -0.00228 -0.00222 -0.00216 -0.00209 -0.00203 -0.00197 -0.00190 -0.00184
-0.00178 -0.00171 -0.00165 -0.00158 -0.00152 -0.00146 -0.00139 -0.00133 -0.00127 -0.00120
-0.00114 -0.00108 -0.00101 -0.00095 -0.00089 -0.00082 -0.00076 -0.00070 -0.00063 -0.00057
-0.00051 -0.00044 -0.00038 -0.00032 -0.00025 -0.00019 -0.00013 -0.00006  0.00000];

  b = g(i);
    t = 0.02;
y = dsolve('(300000* D2y) + (15*Dy) + (20*y) = -(300000*b)', 'y(0) = 0', 'Dy(0) = 0' );
   subs(b)
  a(i) = [subs(y)]
end
a'
plot (a)
%size (g)
%size (t)
```

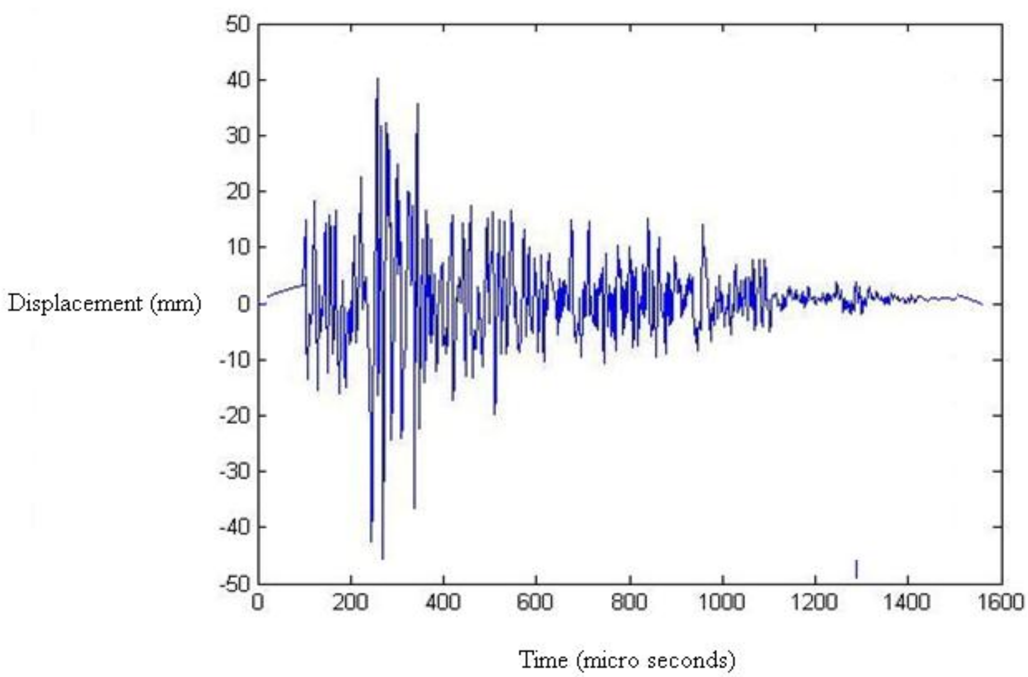

Figure 20 : Displacement vs. time graph of frame

Chapter 5

Conclusion

Conclusions

1 VE dampers are effective in reducing the amplitude of vibration as compared to Frames having no Energy dissipation mechanism
2 Structural response towards VE dampers was good.
3 External VE dampers are easy to install retrofit, effective and cost efficient.
4 It is recommended that external dampers be symmetrically placed wherever possible.
5 Possibility of survival for structure having energy dissipation system installed is much more.
6 Maximum deflection in Frame fitted with damper is 45mm

Chapter 6

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